Image Enhancement:
Spatial domain

Dr. Tushar Sandhan

Introduction

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- Intensity transformations

- Distribution transformation

Spatial domain enhancements

- Transformations
  - intensity transformations
    - negatives
    - logs
    - power-law (gamma)
    - contrast stretching
    - level slicing
    - bit-plane slicing
  - distribution transformations
    - histogram equalization
- Spatial filtering
  - image filtering

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$$s \leftarrow r$$

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Negatives

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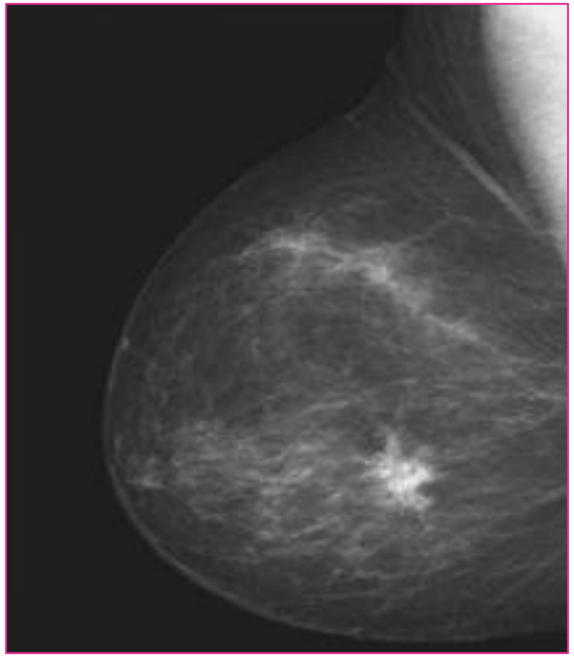

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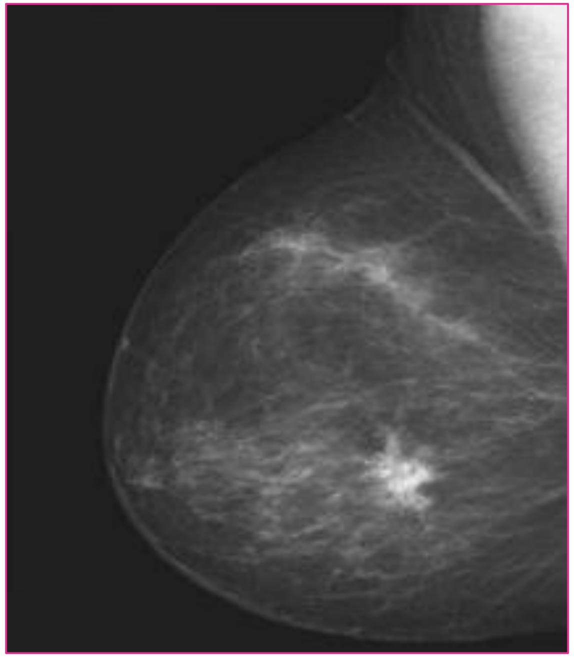

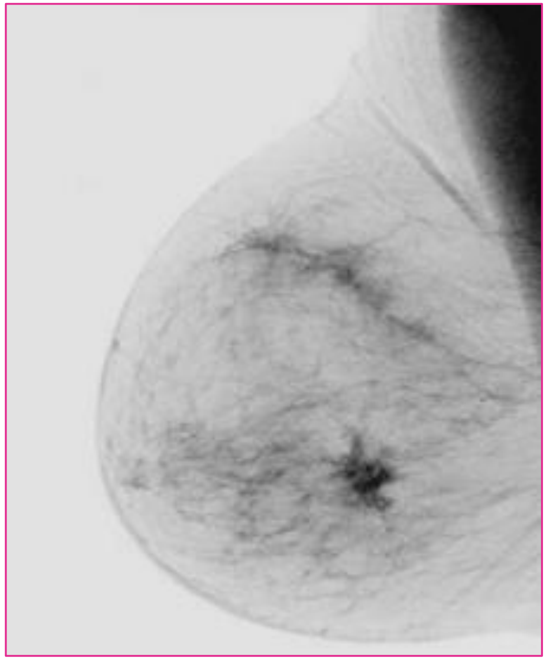

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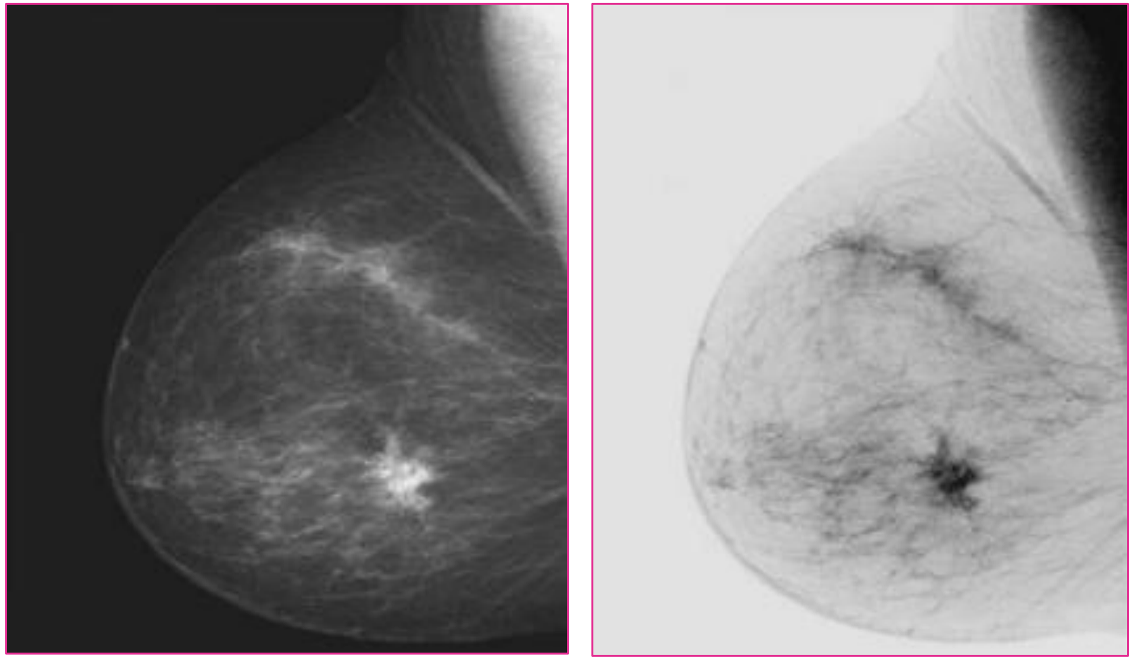

Logs

$$\boxed{s = c \cdot log(1 + r)}$$

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  - used to expand values of dark pixels
  - simultaneously compressing bright pixels
  - compresses dynamic range of images
    - Fourier spectrum

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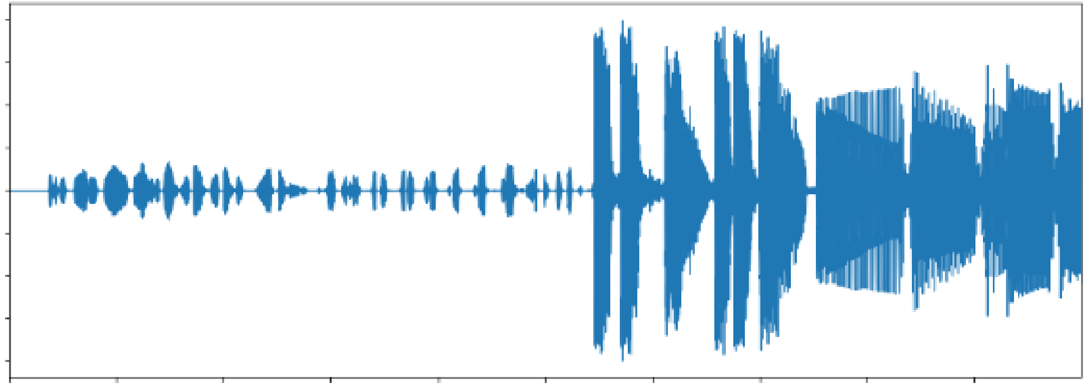

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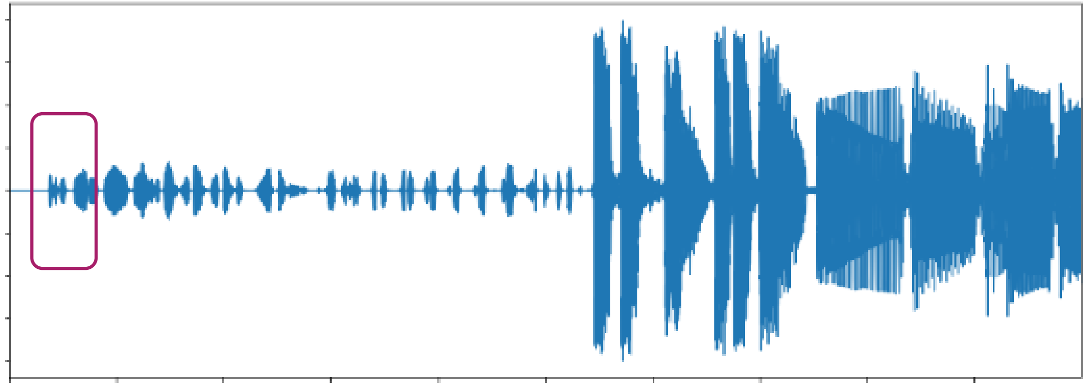

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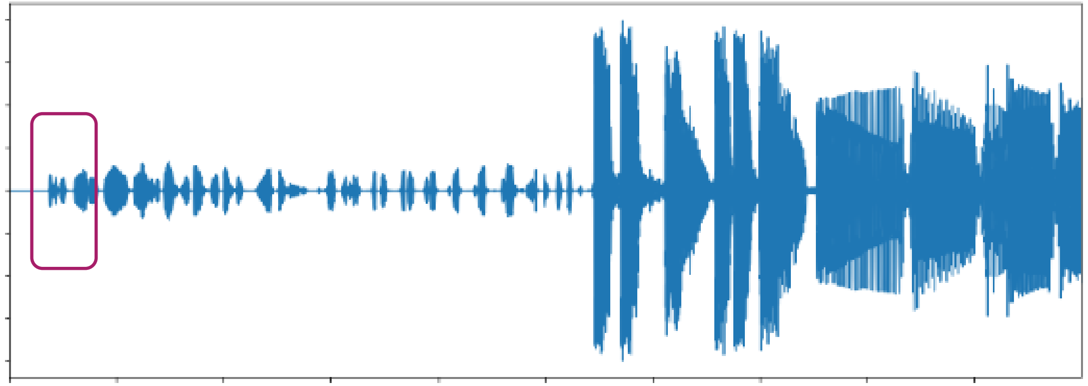

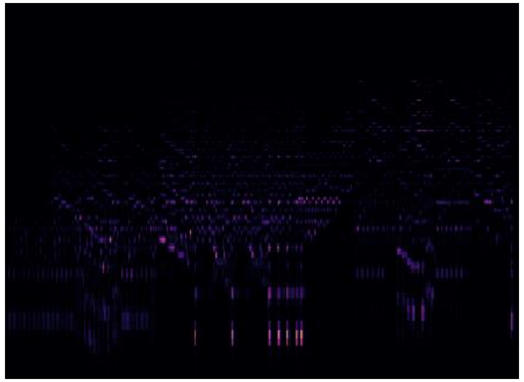

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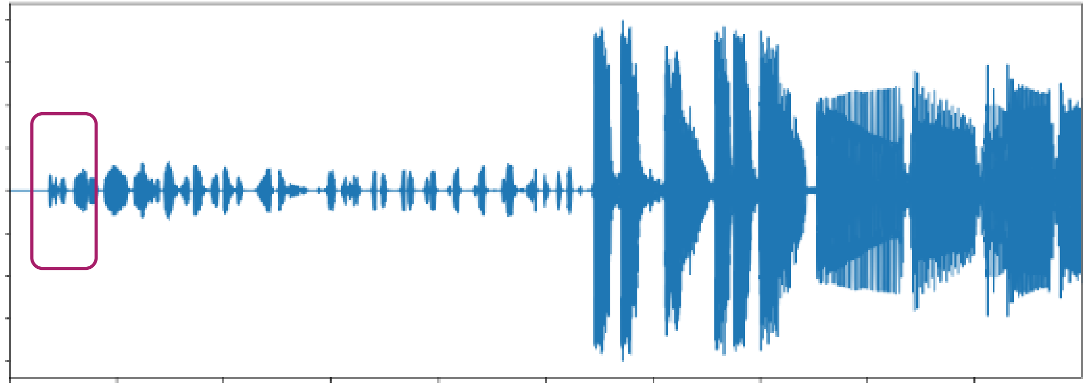
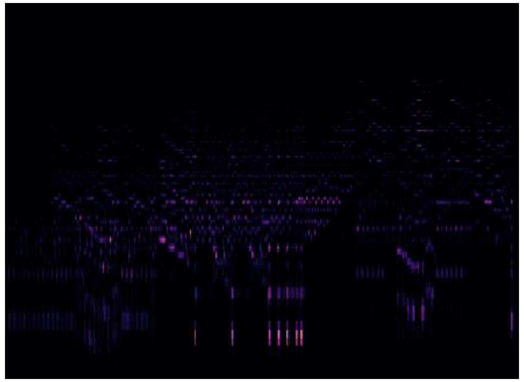
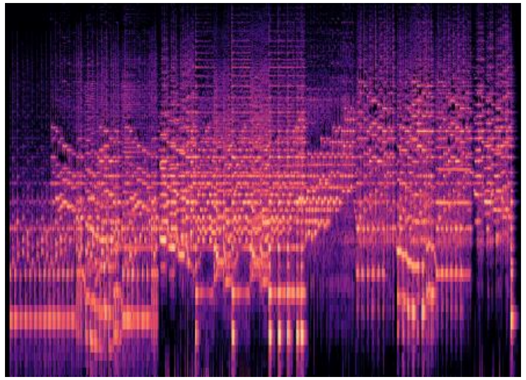




Without Log transform



Log transform done on original image and thn, it has been scaled up to 255, to form the image matrix

Gammas

$$\boxed{s = c \cdot r^{\gamma}}$$

- Power-law transformations
  - sensors respond according to power law
    - CMOS, scanners, printing, displays
    - CRT: intensity to voltage response as power function ($\gamma' = 1.8$~2.5)
  - gamma correction
    - device dependent γ
    - γ variation also varies the color ratios
    - correct color reproduction needs knowledge of γ
  - gamma injection
    - post image processing for contrast manipulation

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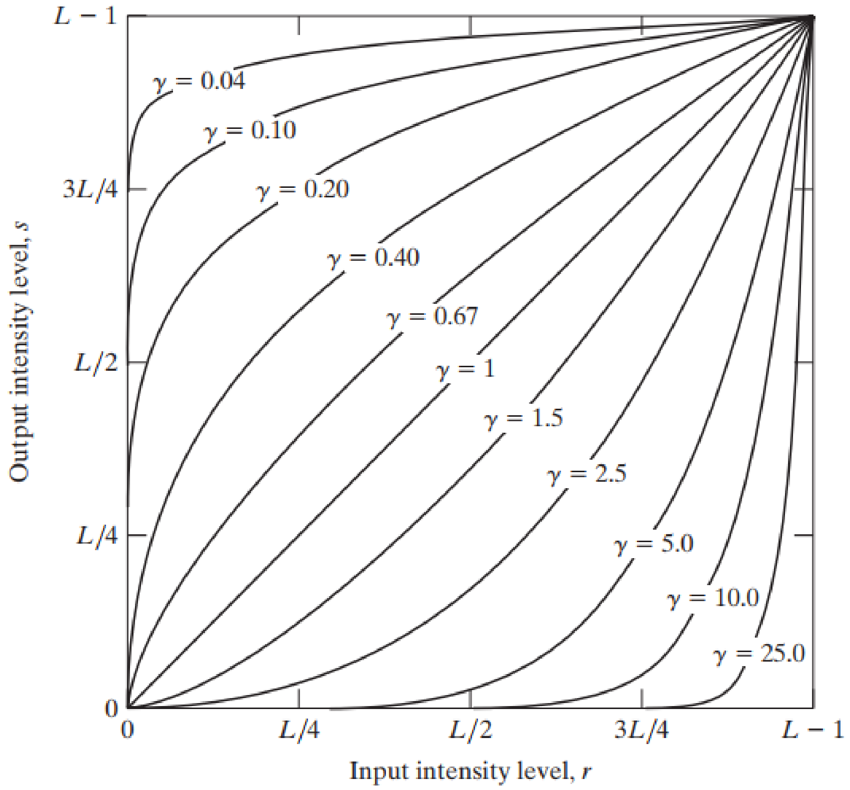

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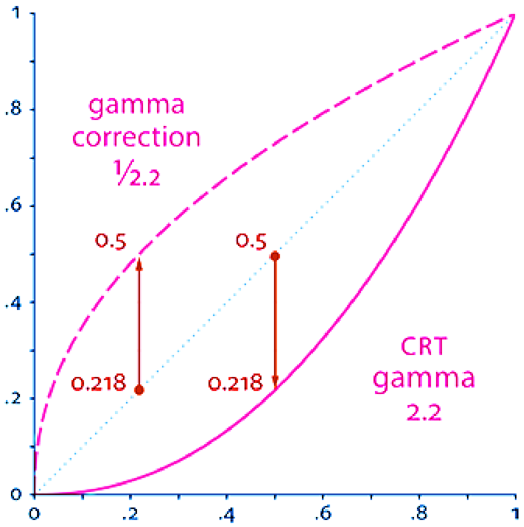

credit: blog.wolfire.com

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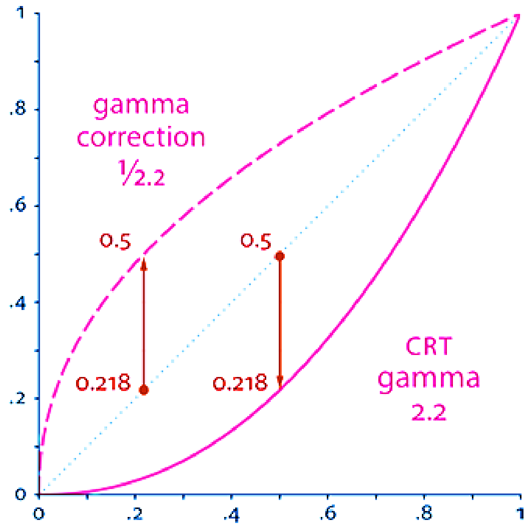

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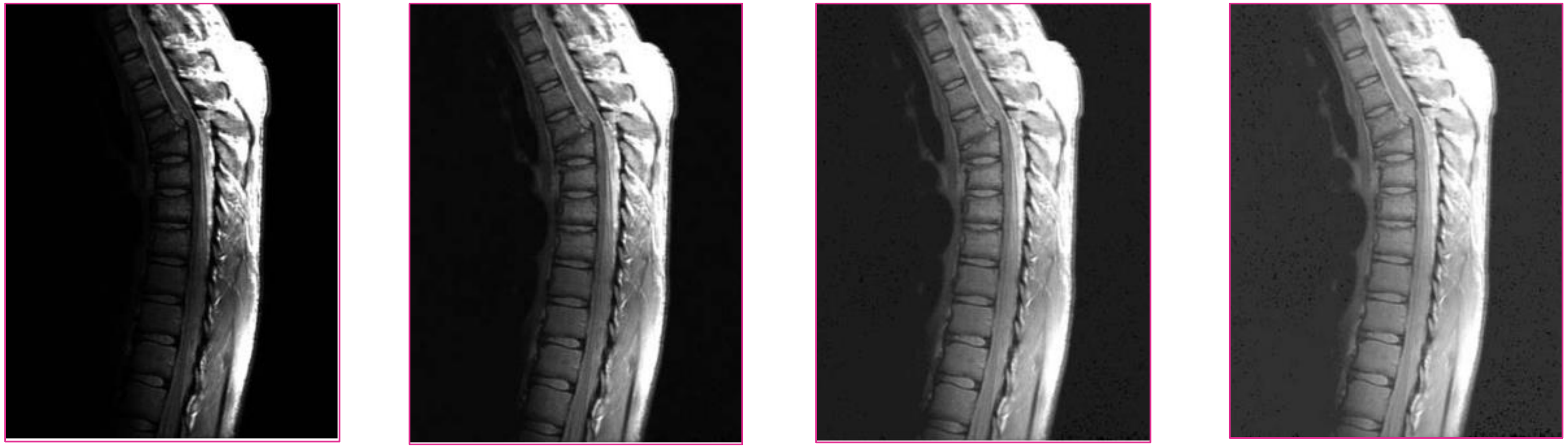

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0.4

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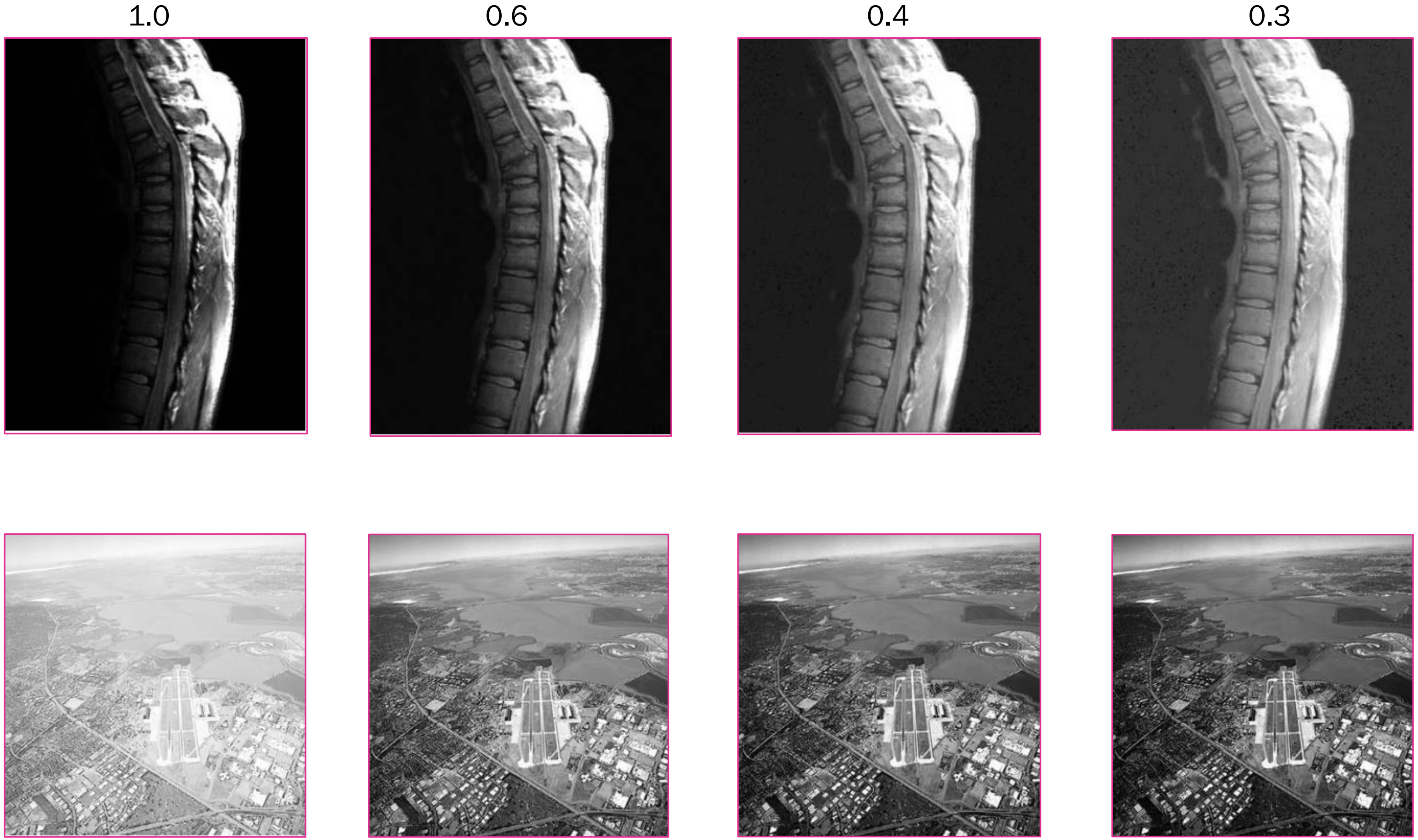

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Enhances Contrast

1.0

0.6

0.4

0.3

1.0

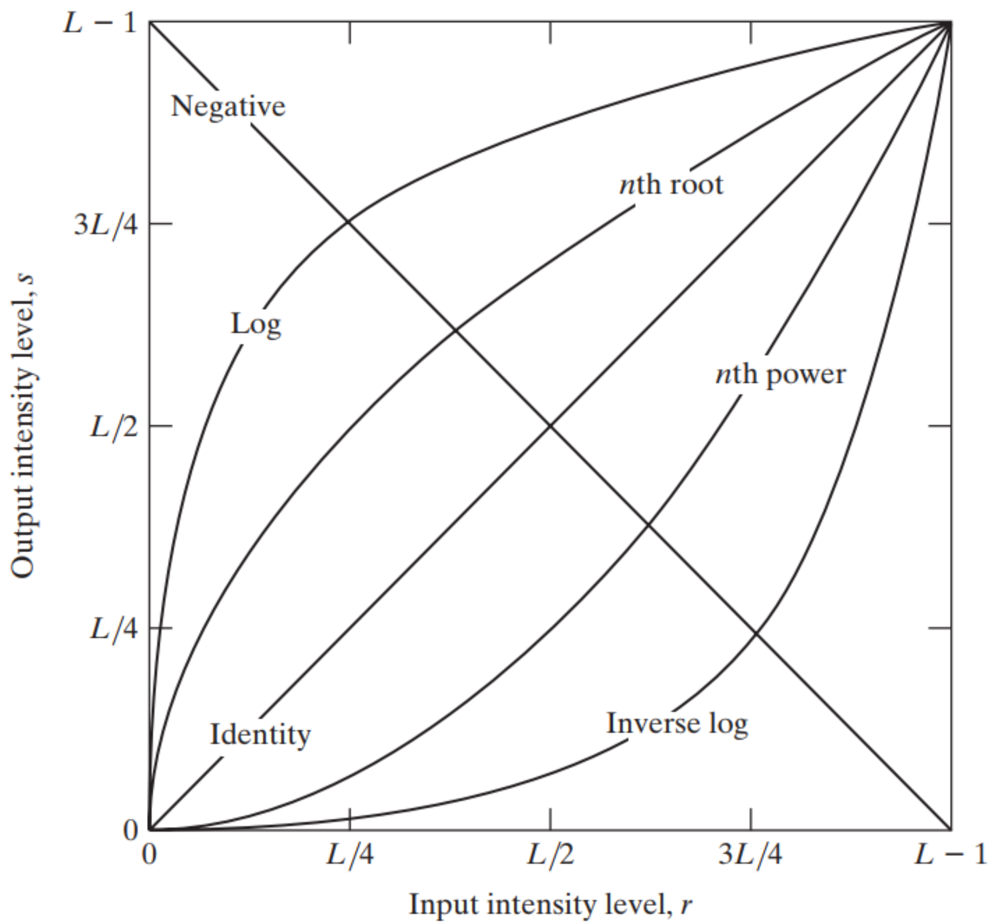
3.0

4.0

5.0

Transformations

- Compositions
  - piecewise combinations
  - piecewise linear
    - many T_i formulated with this
    - need more user input paras



Contrast stretching

- Contrast
  - Low contrast images
    - due to poor illumination, low dynamic range sensors
    - wrong setting of lens aperture

  - full range stretching
    - $(r_1, s_1) = (r_{min}, 0)$
    - $(r_2, s_2) = (r_{max}, L - 1)$
  - thresholding
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$\underbrace{\hspace{6em}}_{\text{pixel ranges}}$

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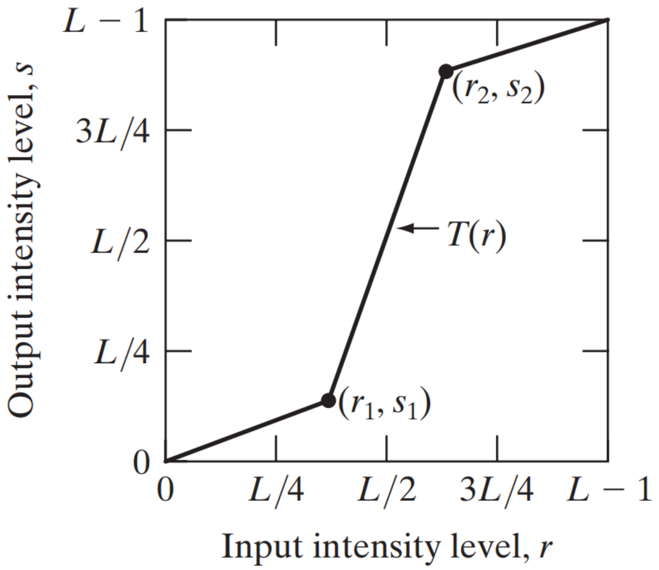

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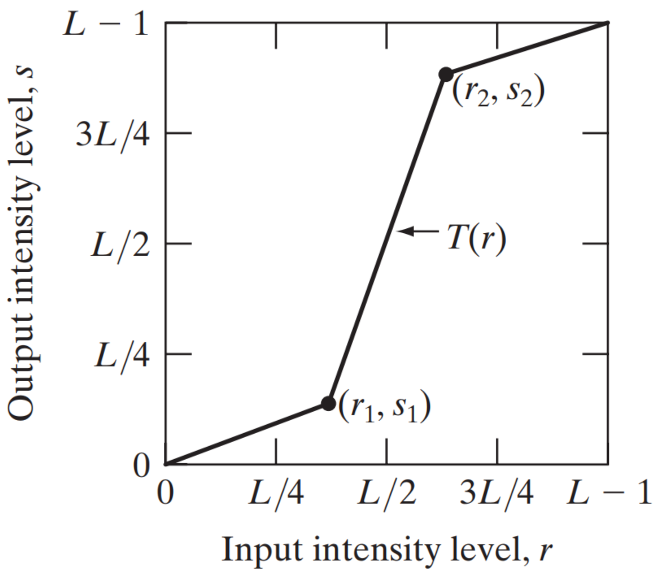

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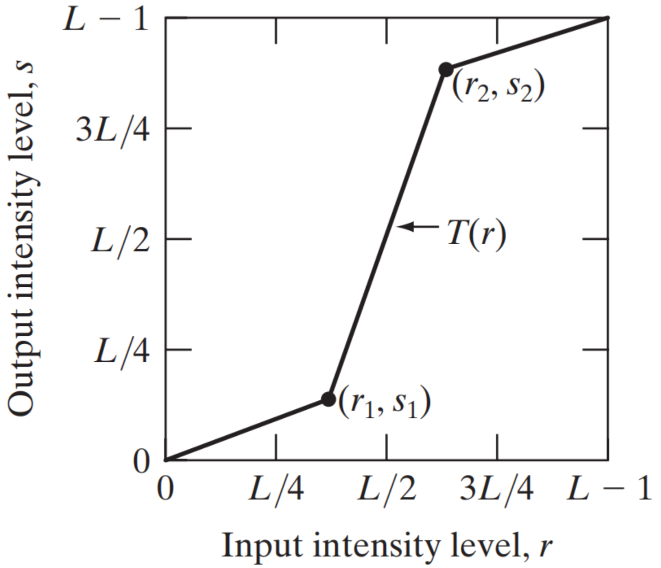

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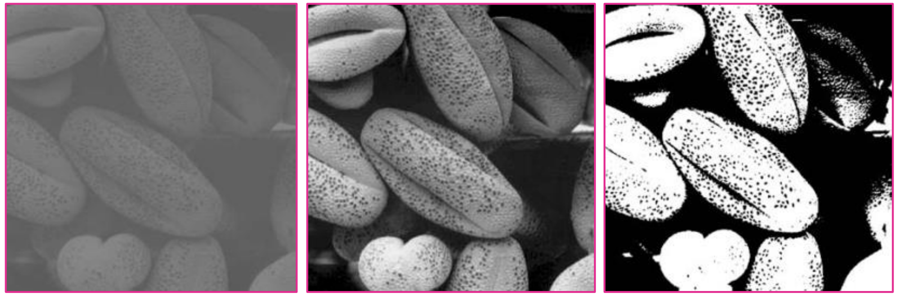

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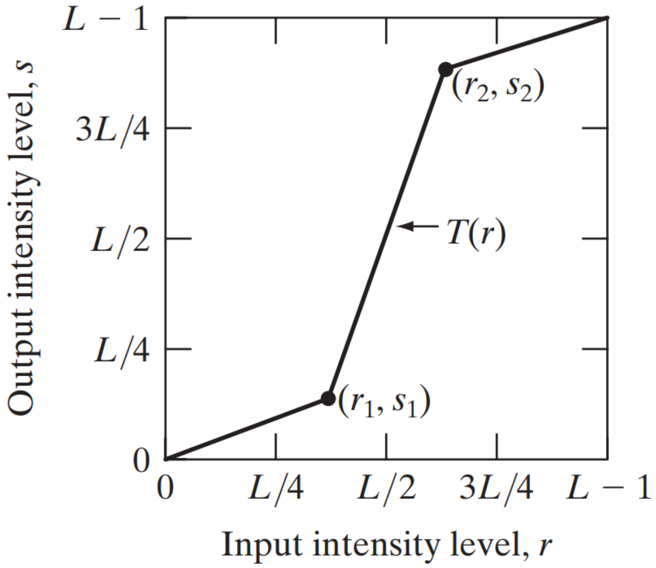

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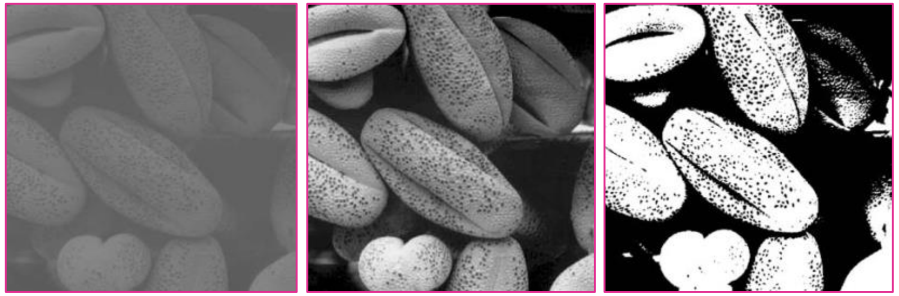
Contrast streching

pixel ranges

SEM image of pollen grains



Level slicing

- Intensity levels
  - local thresholding, stretching
  - enhancing only specific intensities
    - e.g. detecting water, wetland in sat. images

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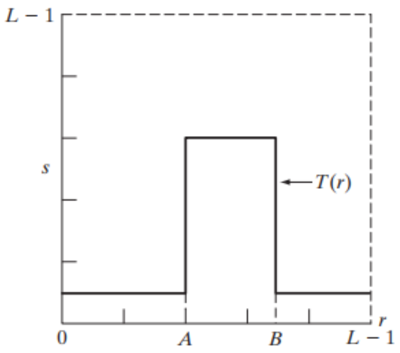

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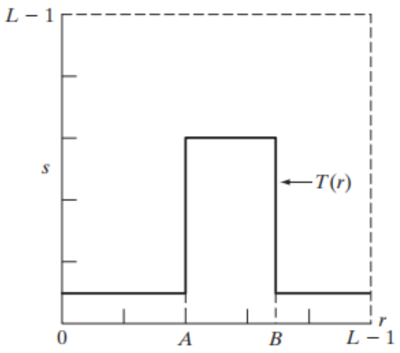

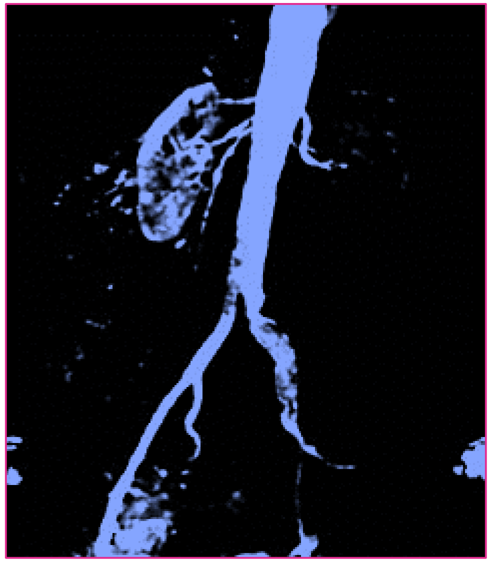

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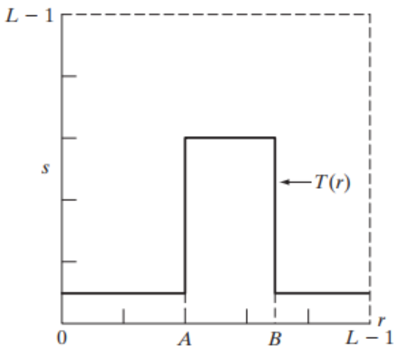

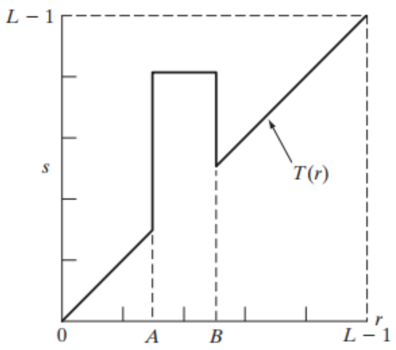

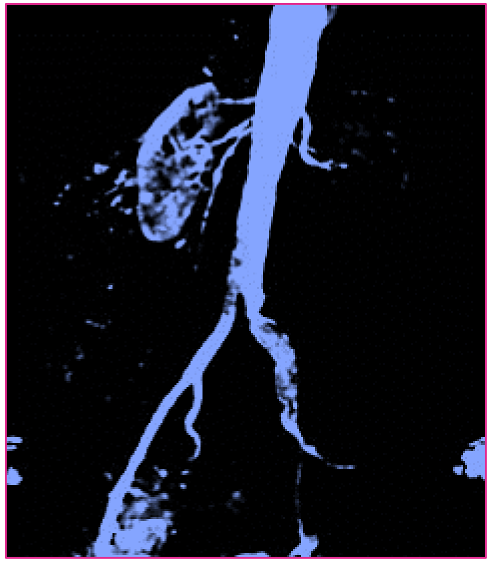

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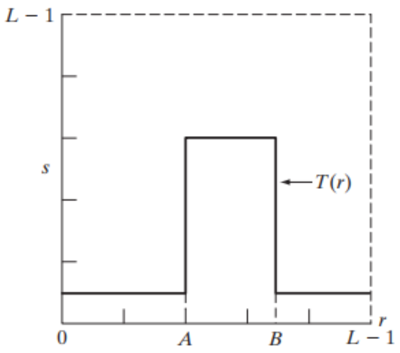
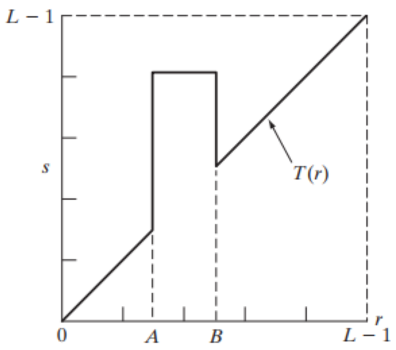
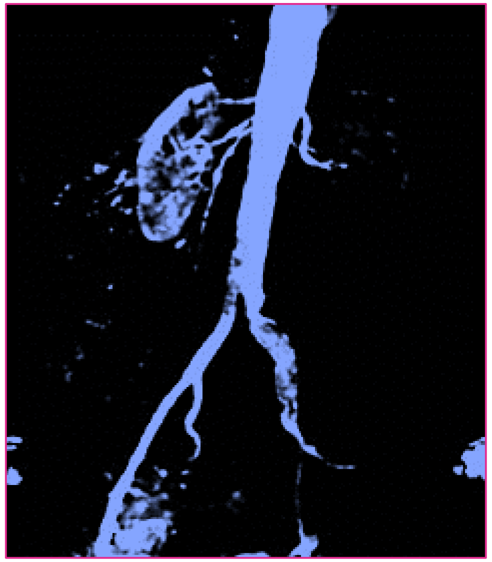
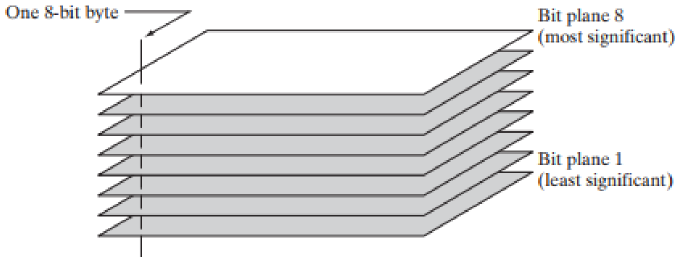






Bitplane slicing

- Bitplanes
  - contribution of each bit for total image appearance
  - gives clue for a compression



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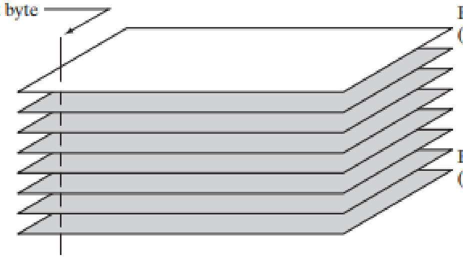


  - slicing

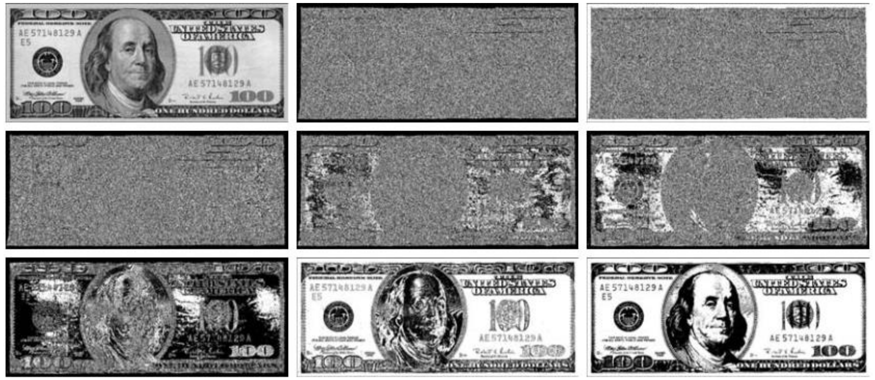
INPUT

Most significant digit separated

2nd

3rd -->

<-- 5th



6th

7th

Least sig digit

CHECK THE NEXT SLIDES HOW THE RECONSTRUCTION WORKS.

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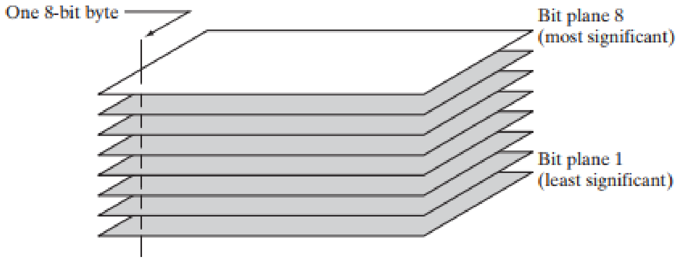

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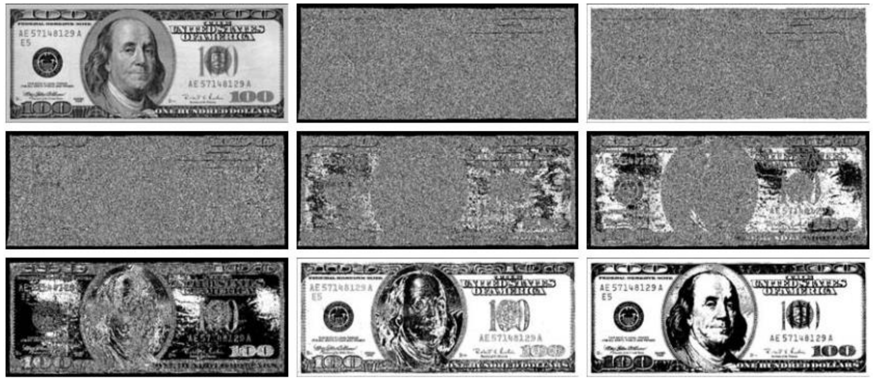

- reconstruction

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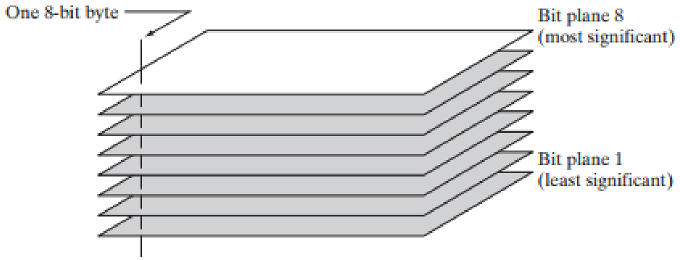

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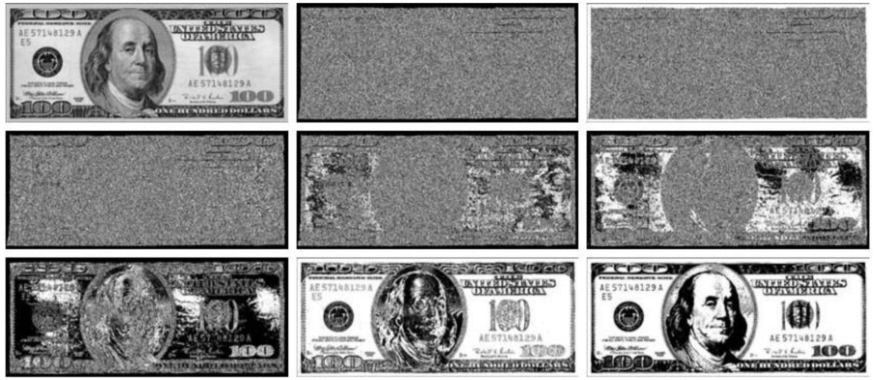

- reconstruction

- bitplanes (8+7)

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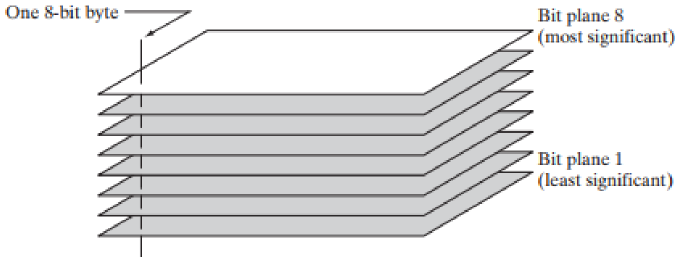

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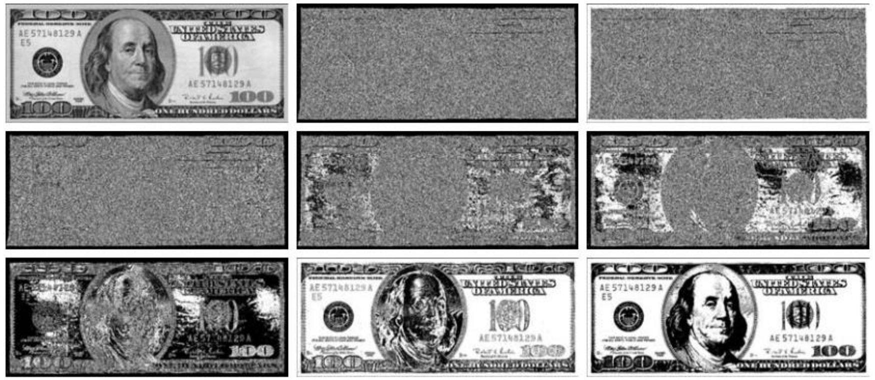

- reconstruction

- bitplanes (8+7)
- bitplanes (8+7+6)

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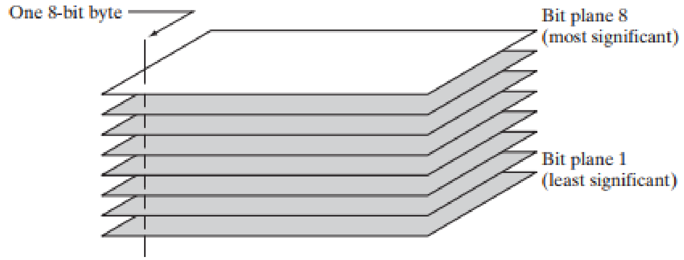

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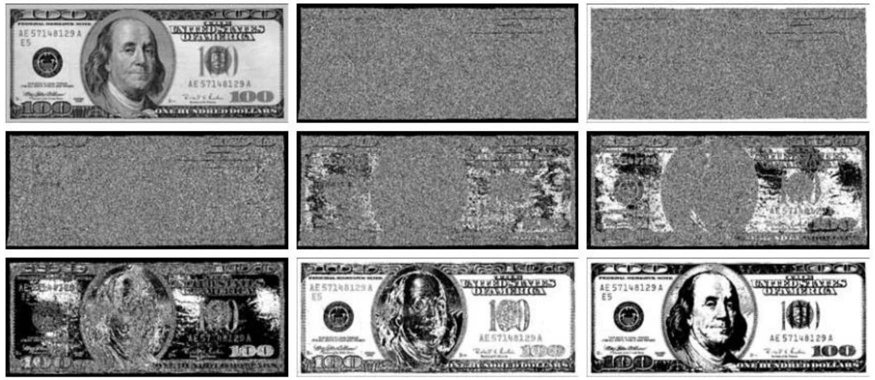

- reconstruction

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- bitplanes (8+7+6)

- bitplanes (8+7+6+5)

Spatial domain enhancements

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$$g(x,y) = \underbrace{T_i(f(x,y))}_{s \leftarrow r}$$

  - distribution transformations
    - histogram equalization

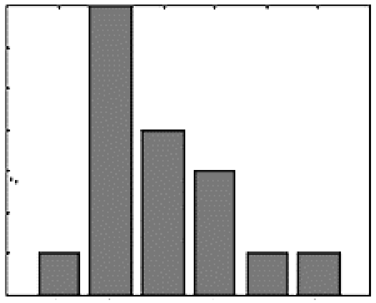
$$g(x,y) = T_i\Big(p\big(f(x,y)\big)\Big)$$

- Spatial filtering
  - image filtering

Histograms

- distribution of discrete intensities
  - distribution is also discrete

4	1	3	2
3	1	1	1
0	1	5	2
1	1	2	2



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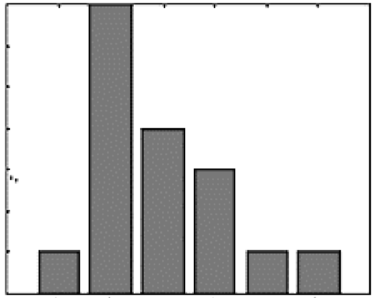

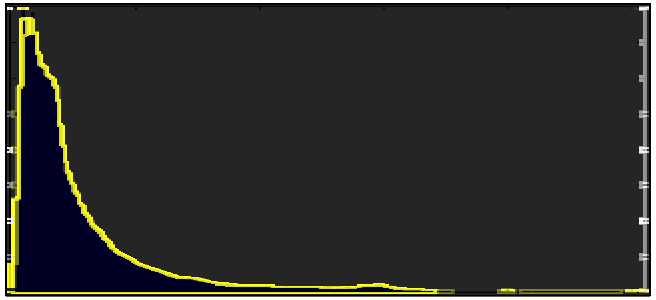

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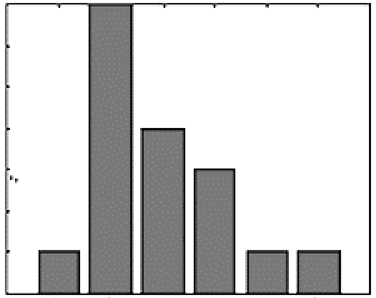

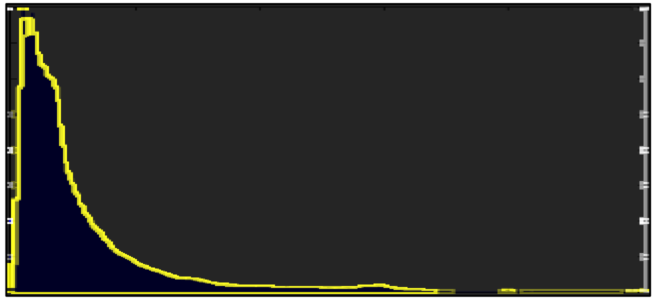

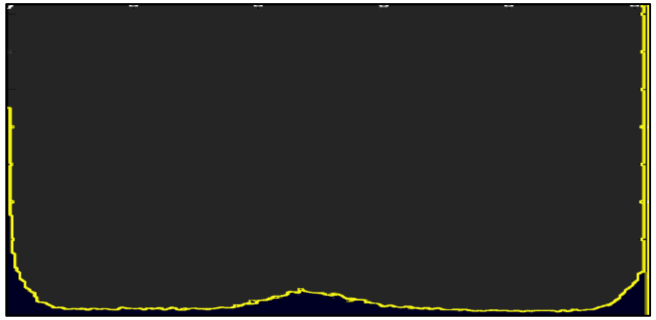

Histograms

- Color images

Histograms

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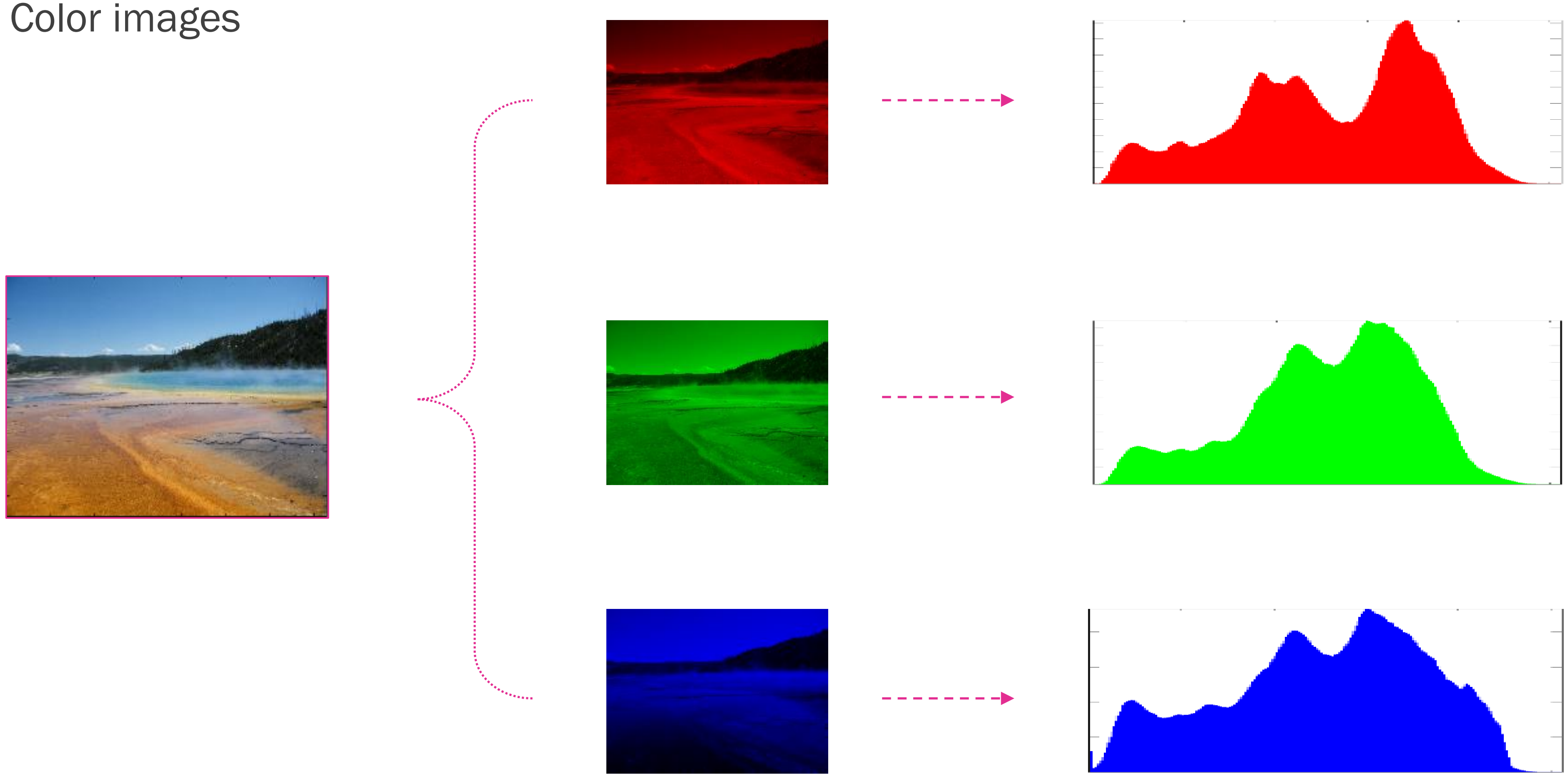
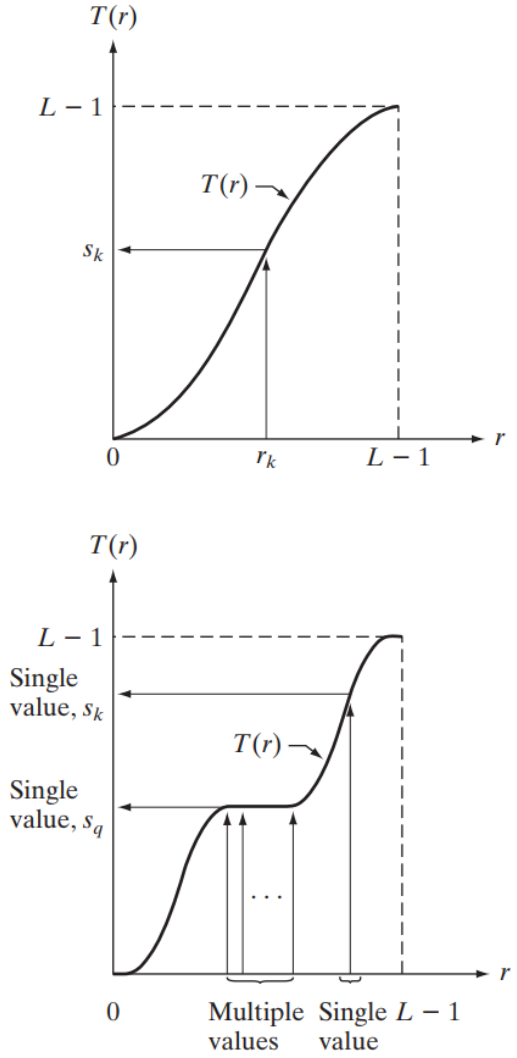


Histogram equalization

- Assume
  - $T(r)$ is monotonic $\uparrow$
  - bounded $0 \le T(r) \le L - 1$
  - variable equivalence
    - to cover all notations

$$s = T(r)$$

$$0 \le r \le L - 1$$



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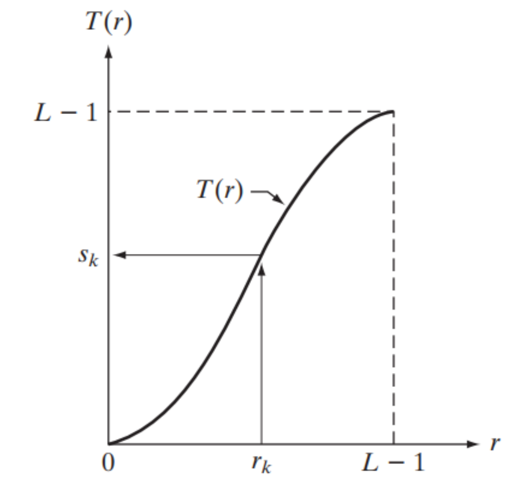

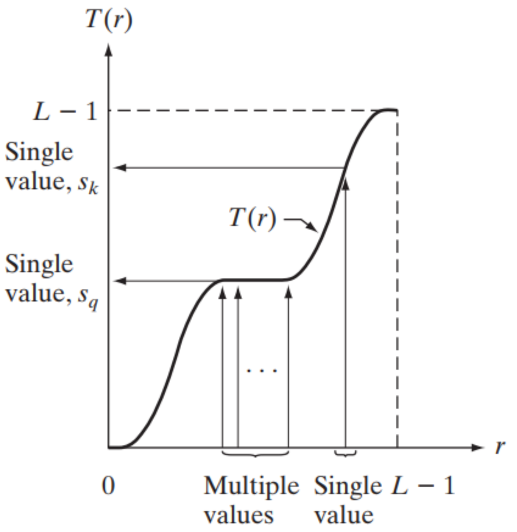

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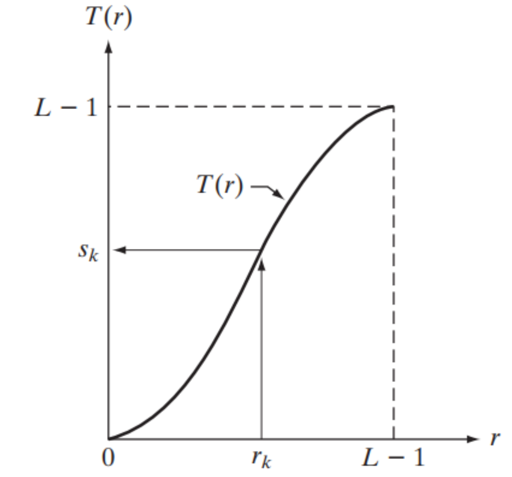

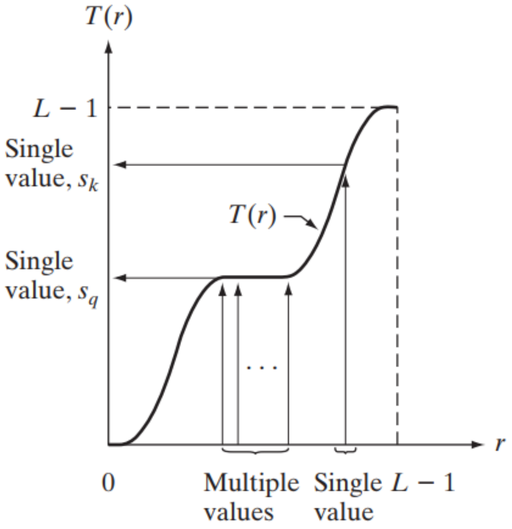

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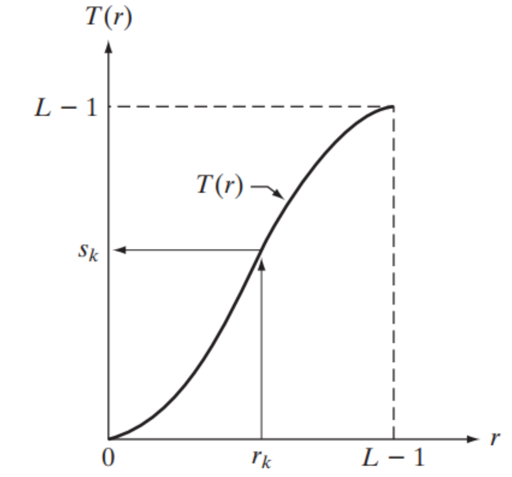

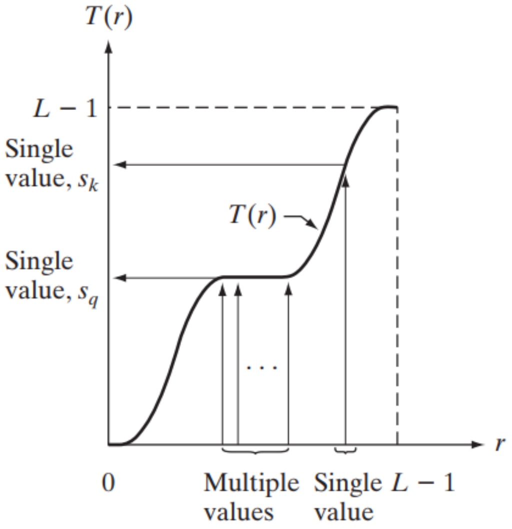

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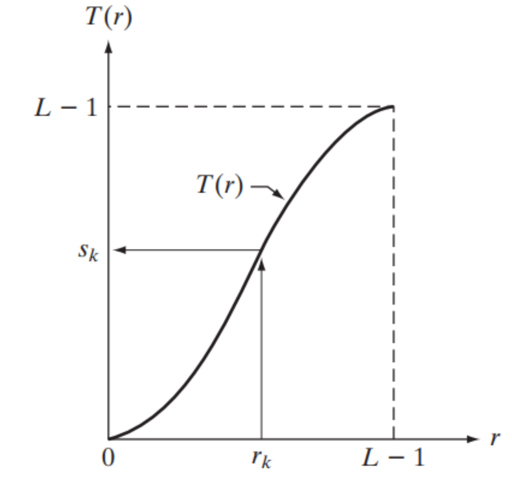

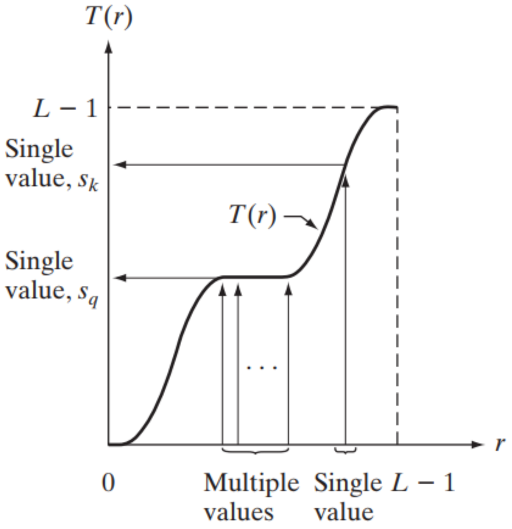

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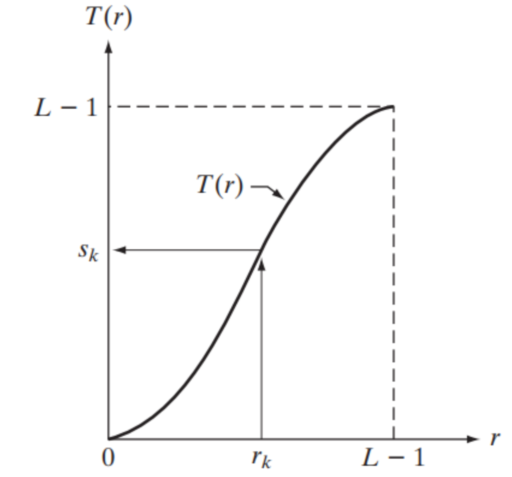

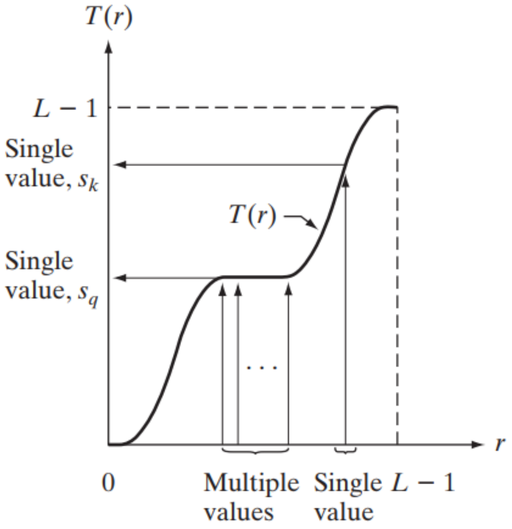

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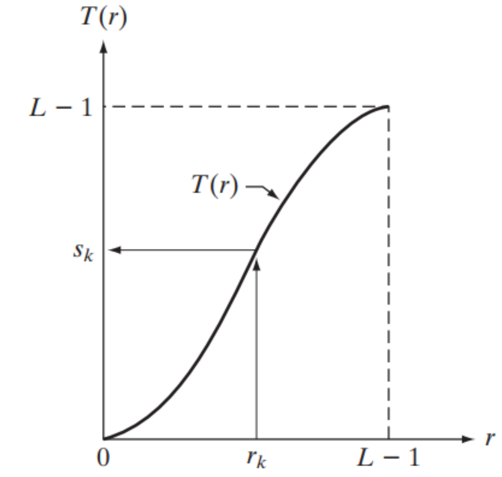
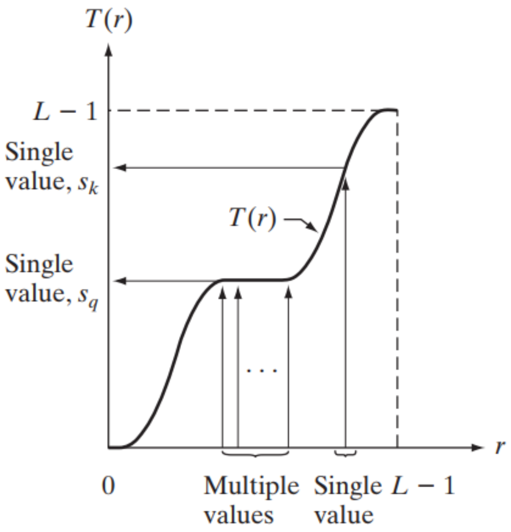


- cumulative function satisfies above properties for $T(r)$



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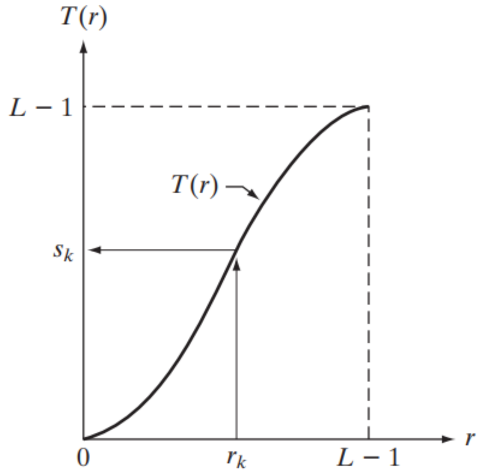
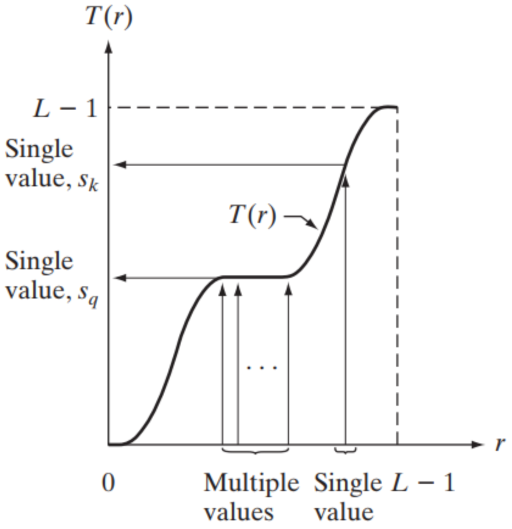


- cumulative function satisfies above properties for $T(r)$

$$s = T(r) = (L-1)\int_0^r p_r(w)\,dw$$

$$Y = T(X) = (L-1)\int_0^X p_X(x)dx$$



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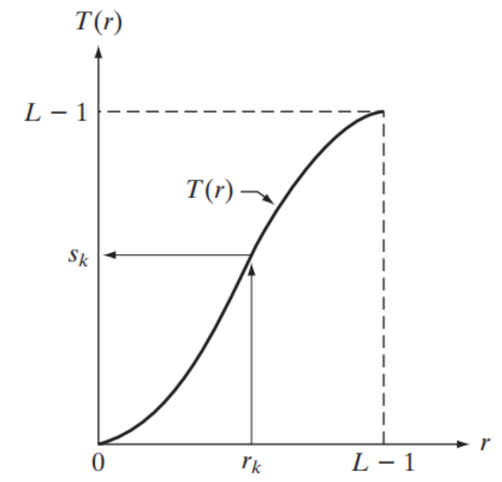

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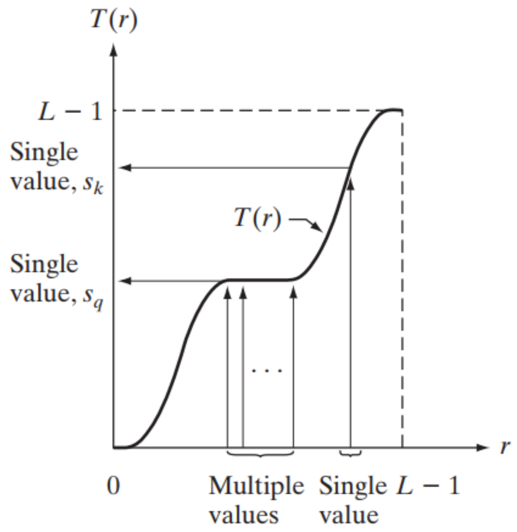
$$Y = T(X) = (L-1)\int_0^X p_X(x)dx$$

$$s_k = T(r_k) = (L-1)\sum_{j=0}^{k} p_r(r_j)$$

$$= \frac{(L-1)}{MN}\sum_{j=0}^{k} n_j \qquad k = 0, 1, 2, \ldots, L-1$$



Histogram equalization

$$Y = T(X) = (L-1)\int_0^X p_X(x)dx$$

$$\begin{tikzcd}[column sep=small] & Y = T(X) \arrow[dl] \arrow[dr] & \\ p_Y(y) & & p_X(x) \end{tikzcd}$$

$T(X)$ is cts & differentiable

What is $p_Y(y)$?

Histogram equalization

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$$\int_0^y p_Y(z)dz = \text{ probability that } 0 \le Y \le y$$

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Histogram equalization

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Histogram equalization

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Histogram equalization

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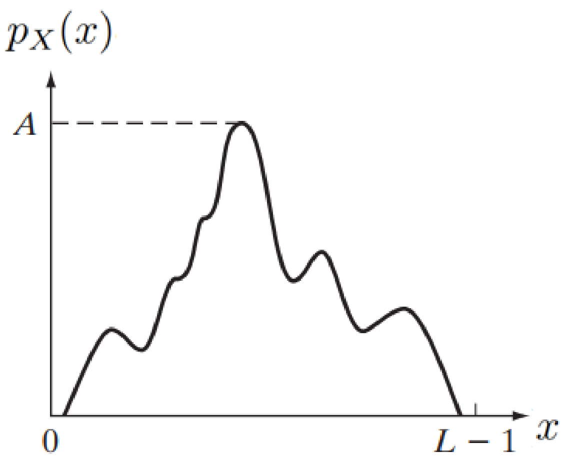

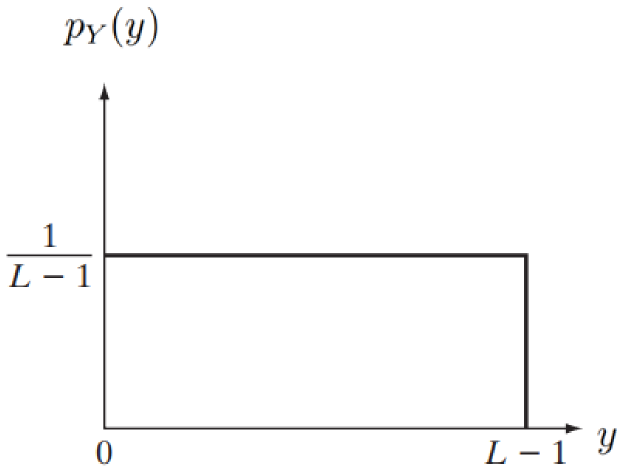

Histogram equalization

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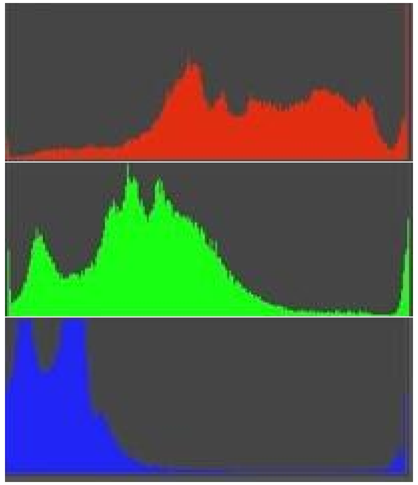

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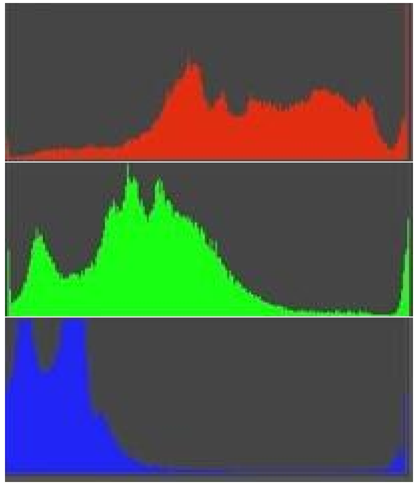

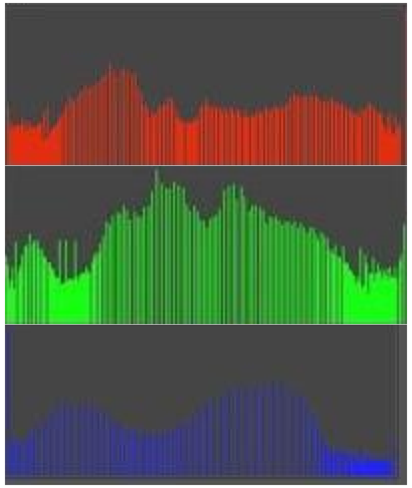

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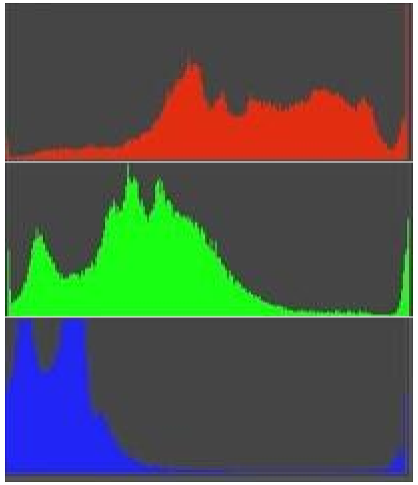

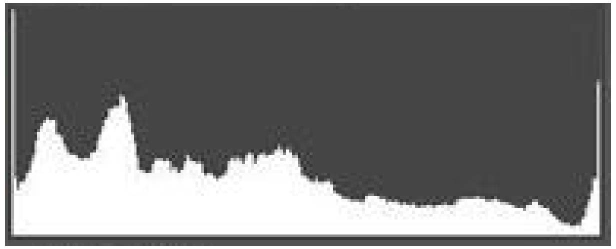

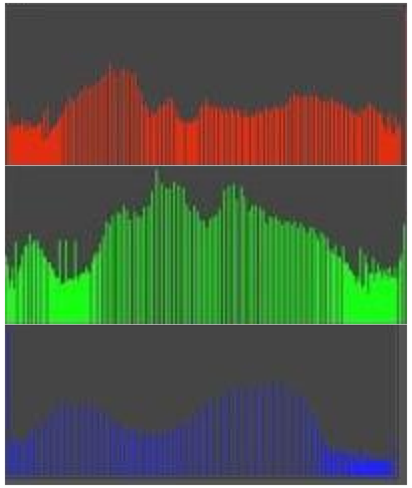

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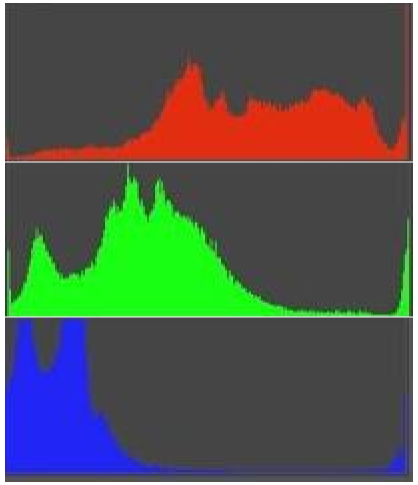

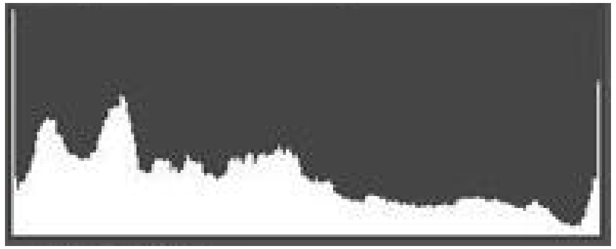

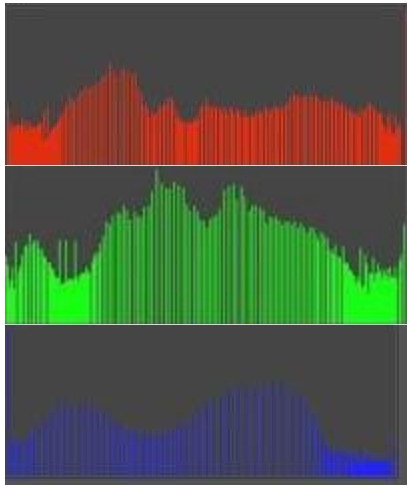

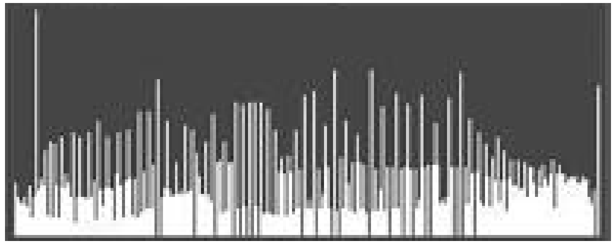

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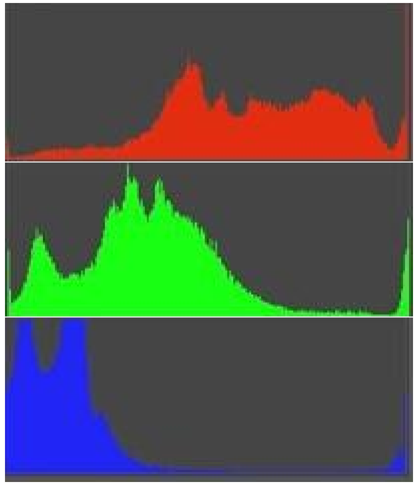

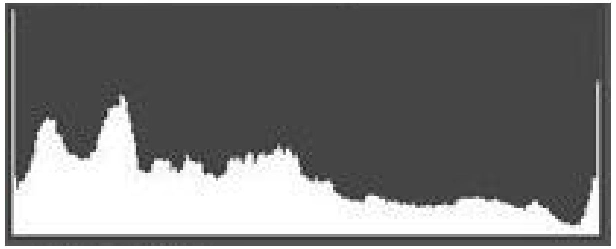

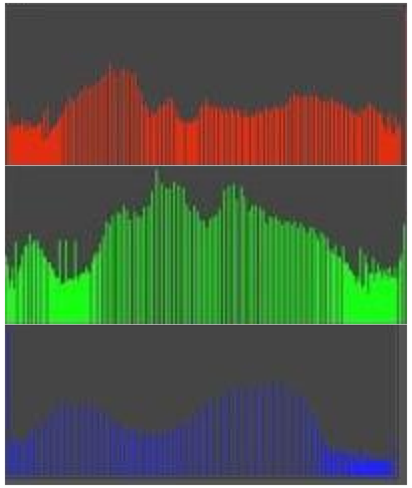

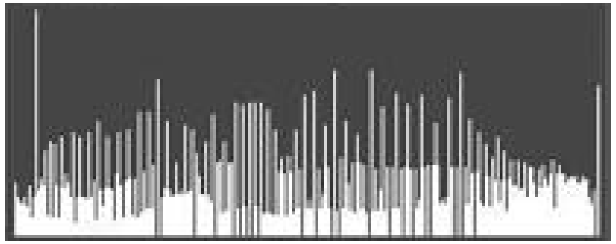

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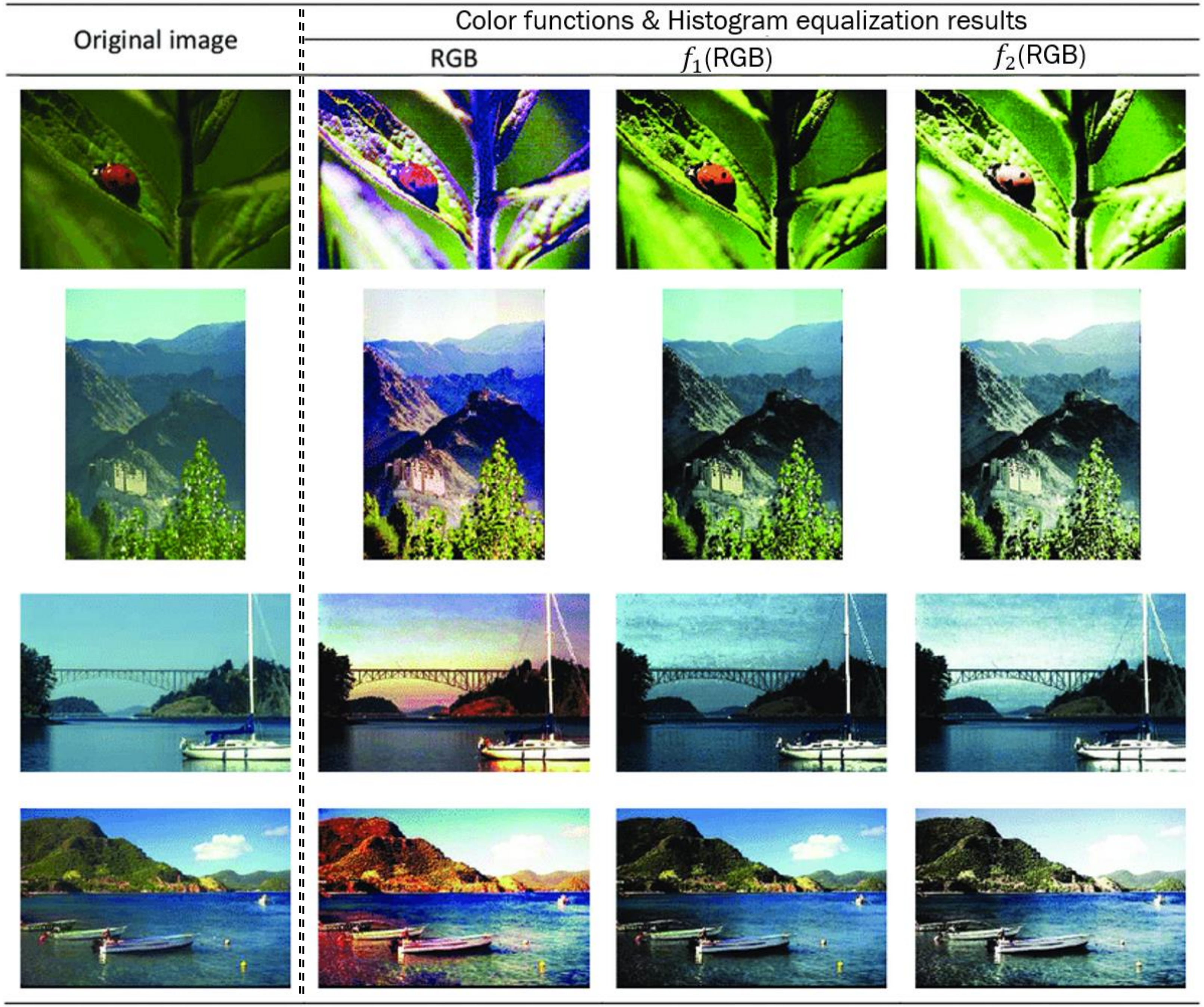
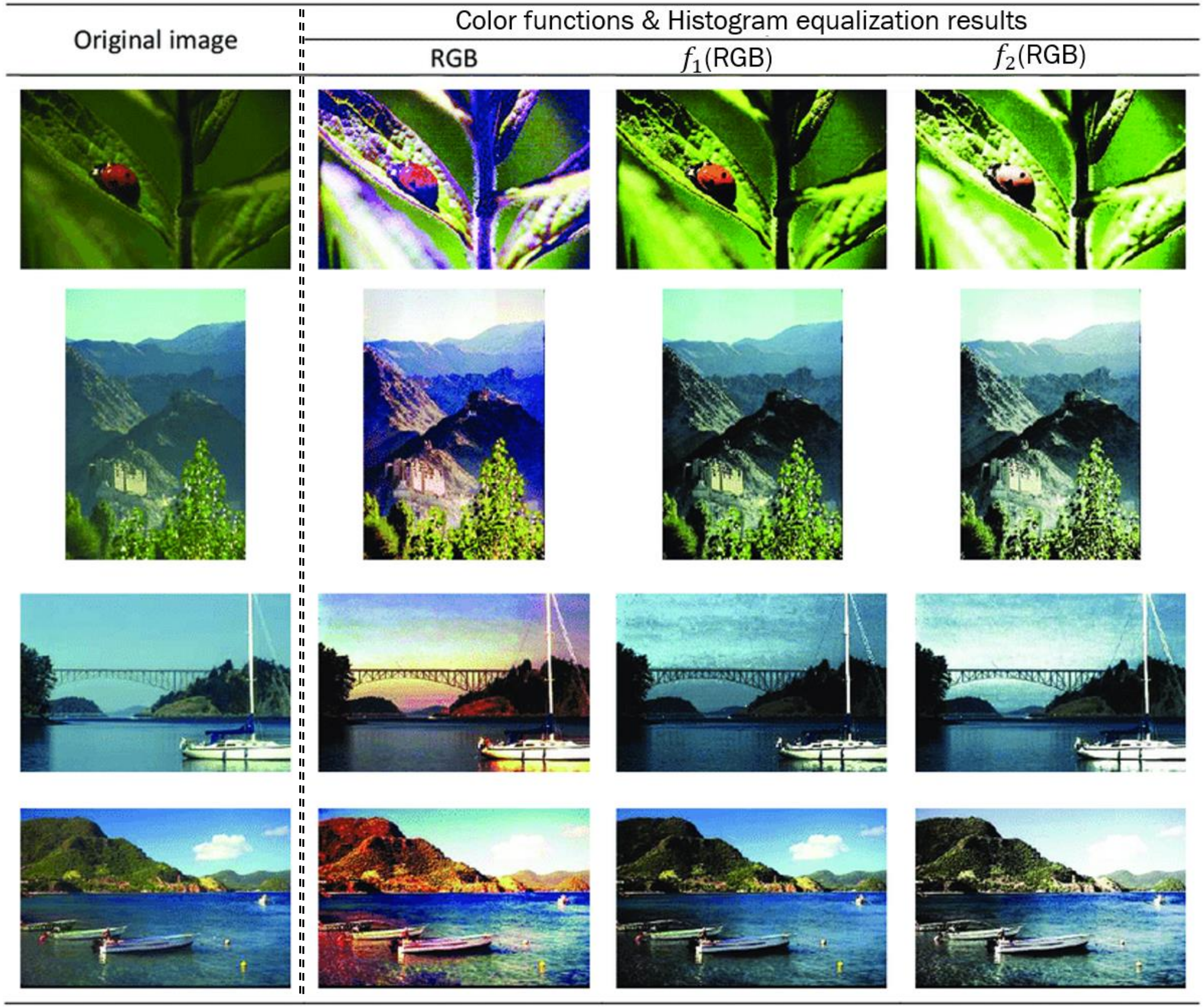


Histogram equalization

- Color conversions
  - colors can be mapped with certain functions
  - mapped images then histogram equalized



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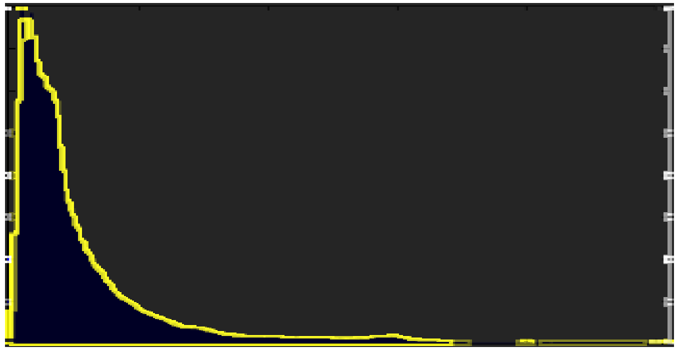
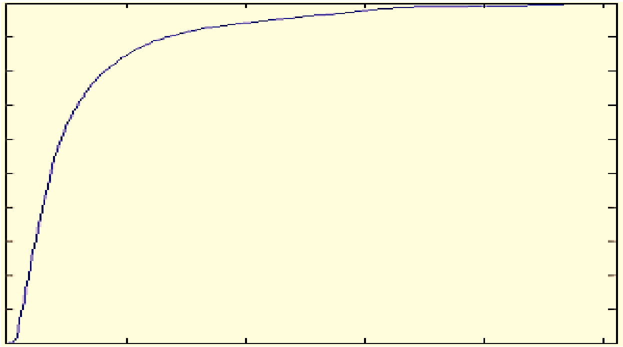
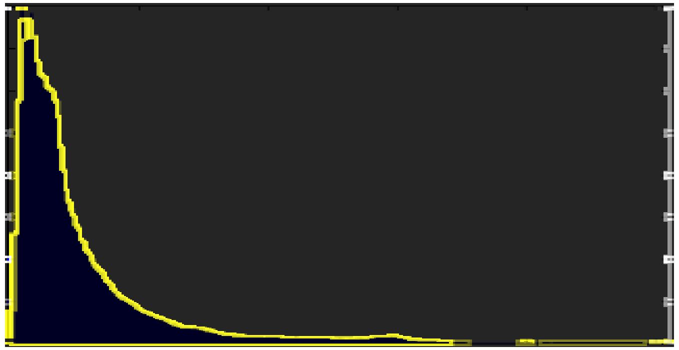
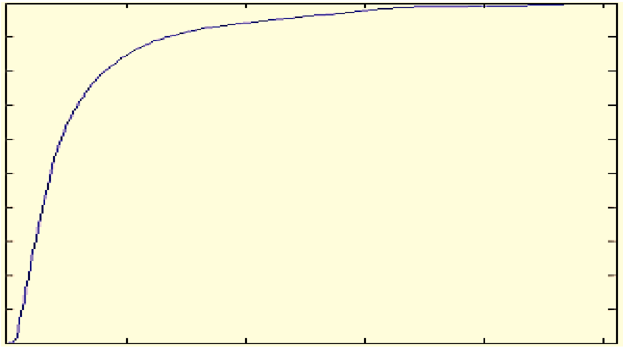
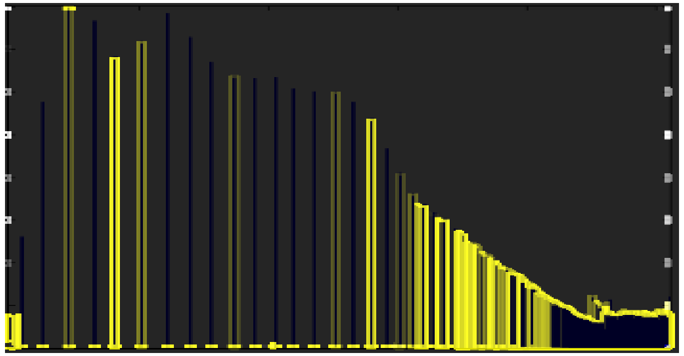
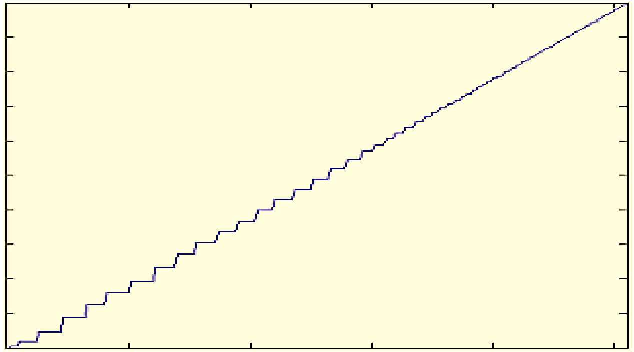




Histogram equalization

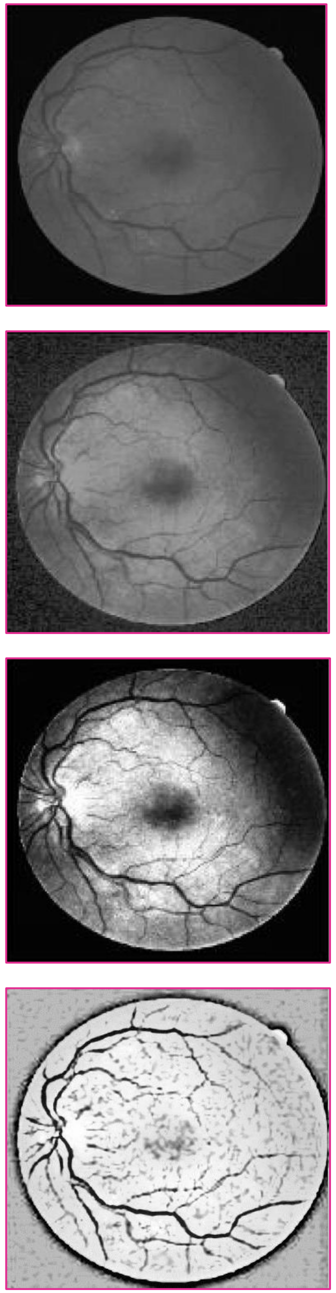



Conclusion

- Intensity transforms
- Distribution transforms

Conclusion

- Intensity transforms
- Distribution transforms



Conclusion

- Intensity transforms
- Distribution transforms

❑ Intensity transformations

- negatives
- logs
- power-law (gamma)
- contrast stretching
- level slicing
- bit-plane slicing

❑ Distribution transformations

- Histogram equalization